DOCUMENT RESUME

ED 478 312 SE 068 143

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| AUTHOR | Romberg, Thomas A.; Collins, Angelo |
| TITLE | The Impact of Standards-based Reform on Methods of Research in Schools. |
| PUB DATE | 2000-00-00 |
| NOTE | 14p.; In: Kelly, Anthony E. and Richard Lesh, Handbook of Research Design in Mathematics and Science Education, Mahwah, NJ, Lawrence Erlbaum, 1999. p73-85. |
| AVAILABLE FROM | Lawrence Erlbaum Associates, Inc., 10 Industrial Avenue, Mahwah, NJ 07430. Web site: http://www.erlbaum.com. |
| PUB TYPE | Books (010) -- Reports - Descriptive (141) |
| EDRS PRICE | EDRS Price MF01 Plus Postage. PC Not Available from EDRS |
| DESCRIPTORS | Curriculum Development; *Educational Change; Educational Principles; Elementary Secondary Education; *Mathematics Education; *Research Design; *Science Education; *Standards |
| IDENTIFIERS | National Council of Teachers of Mathematics |

ABSTRACT

This chapter presents the shift in perspectives about schooling embodied in the National Council of Teachers of Mathematics' (NCTM) Standards-based reform movement, describes the impact of these shifts on the types of questions that need to be answered, and defines the ways in which scholarly evidence needs to be developed. Issues of concern include the need for reform in the content, teaching, and learning of school mathematics and science; the explicit and implicit questions about the impact of reform on the teaching and learning of mathematics and science in American schools; and the degree to which the questions being raised about changes in schooling practices demand particular scholarly methods of collecting reliable and consistent evidence so that school mathematics and science in the United States have the potential to be world class. (KHR)

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# 4 The Impact of Standards-based Reform on Methods of Research in Schools

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In 1990, President George Bush and the nation's governors adopted a set of ambitious education goals for the schools of America to be reached by the year 2000. Then, in 1991, the administration adopted a strategy, labeled *America 2000*, designed to reach those goals (U.S. Department of Education, 1991a). Two of the national goals refer explicitly to mathematics and science: "All students will leave grades 4, 8, and 12 having demonstrated competency in challenging subject matter including...mathematics, science..."; and "U.S. students will be first in the world in mathematics and science achievement." In addition, three other goals refer implicitly to the need for reform in school mathematics and science: the increase in the high school graduation rate, adult literacy (including quantitative and scientific literacy), and professional development of the nation's teaching force (pp. 9–15).

As a nation, if we are to reach these goals, we need to set high expectations of achievement in school mathematics and science for all students, and we need to provide every student the means and the opportunity to achieve those expectations. The focus of the strategy to implement the changes needed in schooling practices to meet these goals has been labeled *standards-based reform* because national standards for the content, teaching, and assessment of

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school mathematics and science have been produced. These standards, developed for mathematics by the National Council of Teachers of Mathematics (1989, 1991b, 1995) and for science by the National Research Council (1996), are to be used to judge the adequacy of what content is taught, how the content is taught, and how student performance is judged in both school mathematics and science.[1]

The purposes of this chapter are to:

- Present the shifts in perspectives about schooling embodied in this reform movement.
- Describe the impact of these shifts on the types of questions that need to be answered.
- Define the ways in which scholarly evidence needs to be developed.

Issues of concern include:

- The need for reform in the content, teaching, and learning of school mathematics and science.
- The explicit and implicit questions about the impact of the reforms on the teaching and learning of mathematics and science in American schools.
- The degree to which the questions being raised about changes in schooling practices demand particular scholarly methods of collecting reliable and consistent evidence so that school mathematics and science in the United States have the potential to be "world class."

Although all of the knowledge about the teaching and learning of mathematics and science is tentative, scholarly evidence gathered in classrooms represents the best data available about the reform efforts and must be derived from diverse sources. Thus, the reform movement demands research in mathematics and science education and demands that reliable evidence must come from field studies of students and teachers interacting in classrooms about

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[1]Also noteworthy are the efforts of Project 2061 of the American Association for the Advancement of Science (Rutherford & Ahlgren, 1990).

important problems leading to the goal of the reform movement—students' understanding of mathematics and science.

## THE NEED FOR REFORM

### The Legacy of Machine-Age Thinking

During the past century, public schools in this country have evolved toward a coherent system designed to transmit a large quantity of information to students through an organized schedule of courses. This system grew out of the machine-age thinking of the industrial revolution. The intellectual content of this age rested on reductionism, analysis, and cause-and-effect explanations (Ackoff, 1972). The machine age was preoccupied with taking things apart. The argument was that if something needed to be explained or a problem solved, it was broken into its components by analysis, and the components studied to determine cause-and-effect relationships. In this sense, the world was regarded as a machine operating in accordance with unchanging laws. It is this machine-age world view that is being challenged by the reform movement in school mathematics and science in the United States.

For schools, machine-age thinking led to information being segmented into subjects, courses, topics, and lessons, eventually getting down to its smallest parts—behavioral objectives. Then, the objectives were related through hierarchies and mechanized through textbooks, worksheets, and tests. Thus, over the last century, the consequences of machine-age thinking have influenced curricula, teachers, instruction, technology, assessment, and classroom environments to such an extent that their features are considered by many as sacrosanct traditions (e.g., the "layer-cake" curriculum; the teacher as teller; five-step instruction in 45-minute class periods; standardized tests; isolated, "egg-crate" classrooms with chalkboards and rows of desks). Traditions in the social sciences, as Popper (1965) once noted, are like laws in the natural sciences: They are to be adhered to until challenged and replaced. Therefore, if we want educational institutions to change, we also must challenge directly the mechanistic traditions underlying current educational institutions, build examples where the conditions for learning with understanding exist, and demonstrate their impact on students' learning. Only then will the implied changes in educational practices occur.

## Why Mathematics and Science Education "Failed"

Several reasons have been given for the claim that the current system is failing to provide all students the opportunity to become mathematically and scientifically literate. Three related reasons are equity, employment, and democratic citizenship. For mathematics, the basis of this claim rests on the fact that nearly half of American students never study any mathematics beyond arithmetic, and the majority of those who do are White males (Mathematical Sciences Education Board [MSEB], 1989). Similarly, for science, at present only 16% of all employed scientists and engineers are women, fewer than 3% are Black, and fewer than 3% are Hispanic (Matyas & Malcom, 1991).

Mathematics and science courses, more than most other curricular offerings in schools, have become a filter in our society that restricts access to knowledge. Too often, women and minority students are encouraged to stop taking mathematics and science or denied any opportunity to study more mathematics and science. This denial has major consequences for employment and citizenship. The MSEB (1989) argued that:

> Of 4 million that begin [school], only 500,000 are still studying mathematics 12 years later. Most students receive little of lasting value from the final mathematics course they study—typically high school geometry or algebra II. Many of those who drop out harbor life-long feelings of guilt or distaste for school mathematics. Some of those who become disenchanted with mathematics become teachers; others help decide educational and research policy for the nation. Very few adults in the United States have had the benefit of successful completion of a mathematics curriculum. (p. 5)

The arguments in A *Nation at Risk* (National Commission on Excellence in Education, 1983) and *Educating Americans for the Twenty-First Century* (National Science Board Commission on Precollege Education in Mathematics, Science, and Technology, 1983) focus on the fact that schools are failing to educate students to be productive employees in today's workplace. Schools, as presently constituted, were the products of an industrial era that has ended. School mathematics and science curricula still reflect the industrial needs of the 1920s, not the workplace or the societal needs of the 1990s. The MSEB (1989, 1990) reinforced the National Council of Teachers of Mathematics, National Research Council, and American

Association for the Advancement of Science positions that to be economically competitive and to practice responsible citizenship in the 21st century, all students will need to know more and a somewhat different mathematics and science than is covered currently in the programs of most American schools.

Furthermore, a recently completed curricula analysis for the Third International Mathematics and Science Study found:

> U.S. mathematics and science curricula reflect juxtaposed goals competing for the same limited resources of time and attention. Our official mathematics and science curriculum statements have no central focus or strategic ideas or approaches to what should be learned in mathematics and the sciences. (U.S. National Research Center for the Third International Mathematics and Science Study, 1996, p. 2)

Such lack of focus in both school mathematics and science has influenced the textbooks, instruction, and, consequently, the achievement of students.

## New Directions

It should not be surprising that there has been a clamor for change. However, documenting the inadequacy of current programs does not identify potentially powerful new practices. One way of approaching the changes needed is to alter our metaphor of schooling. The MSEB (1990) illustrated the kind of modification that is needed: "To the Romans, a curriculum was a rutted course that guided the path of two-wheeled chariots" (p. 4). This metaphor about a path to be followed is an appropriate description of the curricula for most school subjects. The MSEB went on to describe current mathematics curricula in terms of this metaphor:

> Today's mathematics curriculum—a course of study—follows a deeply rutted path directed more by events of the past than the changing needs of the present. Vast number of learning objectives, each associated with pedagogical strategies, serve as mile posts along the trail mapped by texts from kindergarten to twelfth grade. (p. 4)

Furthermore, again quoting MSEB about this path, "Problems are solved not by observing and responding to the natural landscape through which the mathematics curriculum passes, but by mastering time tested routines, conveniently placed along the path" (p. 4). It is this

mechanistic metaphor about what should be taught that is being challenged. Scheffler's (1975) denunciation of this metaphor points the direction for rethinking the structure of a curriculum:

> It is no wonder that this [mechanical] conception isolates mathematics from other subjects, since what is here described is not so much a form of thinking as a substitute for thinking. The process of calculation or computation only involves the deployment of a set routine with no room for ingenuity or flair, no place for guess work or surprise, no chance for discovery, no need for the human being, in fact. (p. 184)

One interpretation of the reform vision of school mathematics presented by the National Council of Teachers of Mathematics in its *Curriculum and Evaluation Standards for School Mathematics* (1989) is that the image of the curriculum, as a tedious, uninteresting path to follow with lots of hurdles to clear, must be changed toward one emphasizing engagement and exploration of problem situations where thinking is valued.

For science education, Hurd (1995) addressed issues similar to those in mathematics education. He grounded the need for revising goals and forms for science education by noting the shifting view of the world:

> We are living in a critical period in our history, characterized by radical changes in how we live, learn and work. We are shifting from an industrial age to a knowledge-intensive society. The traditional purposes for science education and the supporting curriculums are viewed as inadequate ... massive changes have taken place in America altering the character of society including our demography, lifestyles, values, family structures, social institutions, economy, patterns of American life, and the nature and ethos of science. (p. 6)

Hurd explained that current science curricula are rooted in a 200-year-old tradition that places science in a vocational context. In this context, students are to "think like scientists" and "do science" (p. 3). Hurd went on to say that:

> If students are to "be like scientists" they must first learn the language of scientists?... This means learning technical terms, symbols and mathematics expressions characteristic of each discipline studied. As the sciences have progressed over the years, so has the volume of technical

> terms students must learn?... By performing experiments, it was expected that students would gain experience in "doing" science and an appreciation of the objectivity of science?... The requirement that all students get the same answer from an experiment supposedly confirmed the objectivity of a finding. The student's position in these experiments was that of a detached onlooker or spectator. (pp. 3–4)

Hurd described a broad shift in science education curricula:

> As science teaching now stands, all goals, objectives and concepts are *internal* to specific disciplines. The quest in the reform movement is for goals and curriculums in a social context. Briefly, this is a movement from the *esoteric* to the *exoteric* in science teaching. (p. 4, emphasis in the original)

Hurd described some of the characteristics of this shift in science education such as an increased focus on interdisciplinary science research fields that deal with complex systems, the inclusion of science and technology as an integrated system, an increased emphasis on looking toward the future and learning how to be lifelong learners, and increased emphasis on both quantitative and qualitative thinking skills. He predicted that "The trend is toward unity of the sciences and unification of the sciences with society" (p. 8).

A way to start creating new metaphors and practices for mathematics and science education is to consider mathematics and science knowledge, as any field of knowledge, organized into several related domains (or "conceptual fields;" Vergnaud, 1982). This domain view differs from the mechanical view in at least two important ways. First, the emphasis is not with the parts of which things are made but with the whole of which they are part (how concepts and skills in a domain are related) and, in turn, how those parts are related to other parts, other domains, and ideas in other disciplines. Second, this conception does not rest on a deterministic base of fundamental parts from which everything else is created. Instead, it rests on the signs, symbols, terms, and rules for use—the language that humans invent to communicate with each other. From this perspective, Greeno (1991) proposed a different metaphor:

> Students develop understanding when a domain is thought of as an environment, with resources at various places in the domain. In this metaphor, knowing is knowing your way around in the environment and knowing how to use its resources. This includes knowing what resources are available in the environment as well as being able to find and use those resources for understanding and reasoning. Knowing includes interactions with the environment in its own terms—exploring the territory, appreciating its scenery, and understanding how its various components interact. Knowing the domain also includes knowing what resources are in the environment that can be used to support your individual and social activities and the ability to recognize, find, and use those resources productively. Learning the domain, in this view, is analogous to learning to live in an environment: learning your way around, learning what resources are available, and learning how to use those resources in conducting your activities productively and enjoyably. (p. 175)

To engineer curricula based on this domain knowledge view, what is needed is a collection of problem situations that engage students so that they explore each domain in a structured manner. To accomplish this, two distinct dimensions need to be considered. The first is that the domain needs to be well mapped. This is not an easy task, as Webb and Romberg (1992) argued:

> knowledge of a domain is viewed as forming a network of multiple possible paths and not partitioned into discrete segments?... Over time, the maturation of a student's functioning within a conceptual field should be observed by noting the formation of new linkages, the variation in the situations the person is able to work with, the degree of abstraction that is applied, and the level of reasoning applied. (p. 47)

This dimension demands that the key features and resources of the domain that are important for students to find, discover, use, or even invent for themselves are identified.

The second dimension is that activities need to be identified that encourage students to explore the domain, and then the activities need to be organized in a structured manner that allows for such exploration. Doing both is not easy. For example, although there is no doubt

that many interesting activities exist or can be created, "Do they lead anywhere?" is a serious question. Keitel (1987) argued that an activity approach in mathematics may lead to "no mathematics at all," and Romberg (1992b) stated that:

> Too often a problem is judged to be relevant through the eyes of adults, not children. Also, this perception is undoubtedly a Western, middle-class, static vision. Concrete situations, by themselves, do not guarantee that students will see relevance to their worlds, they may not be relevant for all students nor prepare them to deal with a changing, dynamic world. (p. 778)

In summary, there is a need to change the curriculum metaphor from following a path, to exploring an environment. As the new metaphor acquires detail and exemplars, it needs to describe how students engage in exploration as well as current understandings of the nature of science and mathematics as it relates to society. The new metaphor needs to be powerful in promoting the design of activities that require students to explore valued knowledge, and it should include multiple ways for students to demonstrate understanding.

## Implications of These Shifts for Schooling

The standards-based reform efforts imply that all students need to learn more, and often different, mathematics and science and that instruction must be revised significantly. The key notions embedded in this statement are the following:

- Teaching mathematics and science to "all students" emphasizes the fact that all need to be mathematically and scientifically literate if they are to be productive citizens in the 21st century. In particular, this emphasis on all students includes the traditionally underrepresented groups in mathematics and science—women, persons of color, and persons with disabilities.
- "Learn more" has two implications. First, in all mathematics and science courses, students need to learn more than how to manipulate symbols or to memorize terms. This implies that emphasis in every course should shift from coverage of a lot of procedures and facts toward a more indepth examination of selected important topics (the motto is "less is more"). Second, all students should expect to study mathematics and science every year that they are in school.

- "Often different mathematics and science" refers to the fact that, for mathematics, the mathematics that all students need to learn includes concepts from algebra, geometry, trigonometry, statistics, probability, discrete mathematics, and even calculus; for science, all students need to develop a rich and useful understanding of the major ideas through a process of inquiry and, in so doing, come to understand and master the process of inquiry.
- "To learn" means more than to be shown or to memorize and repeat. Learning involves asking, investigating, formulating, representing, reasoning, and using strategies to solve problems, and then reflecting on the mathematics and science being used.
- "Revised" instruction implies that classrooms need to become discourse communities in which conjectures are made, arguments presented, strategies discussed, and conversations the norm.

It is in classrooms that exhibit these features that research on the effects of reform needs to be conducted.

## RESEARCH QUESTIONS

Propelled by the need to educate all of America's students to levels of achievement in mathematics and science not thought possible over a decade ago, the challenge of the reform movement is to create classrooms where all students have the opportunity to understand mathematical and scientific ideas. This assertion is based on the belief that there is a direct and powerful relationship between student understanding and student achievement. In fact, the way to achieve the high expectations that we have for all students rests on their understanding of important mathematical and scientific ideas taught in school classrooms by professional teachers. This challenge needs to be addressed directly by researchers so that real change in the teaching and learning of mathematics and science occurs in the next decade. A sustained research program, conducted collaboratively with school personnel in school classrooms, needs to be carried out.

There is a pressing need to investigate how classrooms that promote understanding in mathematics and science can be created. Although much extant work can help to address this

need, there are important gaps in our knowledge. To guide specific research studies, we suggest that attention be focused on the following eight general questions:

1. How is learning for understanding in both school mathematics and school science best characterized?

2. What are the important ideas in both school mathematics and school science that we expect students to understand?

3. What are the critical instructional features in classrooms that promote understanding for all students?

4. What is the appropriate role for teachers in such classrooms? (How can they be helped to assume their appropriate role effectively? How can changes in teachers' beliefs and practices be made self-sustaining?)

5. What is the impact on students' achievement of their understanding of the important ideas in mathematics and science? (That is, what information can be collected to demonstrate that students have grown in their understanding of the important ideas in both disciplines and to show their high levels of achievement?)

6. What organizational capacity—in the school and larger community—is required to support and sustain the development of classrooms that promote understanding?

7. How can we ensure the equitable distribution of opportunities to learn mathematics and science with understanding?

8. What strategies are effective in providing both information and support to policymakers, school administrators, and teachers so that they utilize the findings to create and support classrooms that promote understanding in mathematics and science?

## RESEARCH METHODS

As Lesh and Kelly (chap. 9, this volume) and Mestre (chap. 7, this volume) have argued, an investigator must match the methodology to the research questions. The specific research questions based on the eight general questions raised previously demand particular scholarly methods of collecting evidence and drawing inferences from that evidence. Because an object of the reform movement is classrooms that promote understanding, field studies of students and teachers interacting in classrooms about important problems leading to students' understanding of mathematics and science are warranted.

Although such field studies usually will involve experimentation, in that the impact of new content, strategies, instructional procedures, and so forth are being investigated, this does not mean that the classical experimental methods are appropriate (e.g., those summarized for education by D. T. Campbell & Stanley, 1963). Experimentation in reform classrooms occurs in a complex social environment that must be examined in a manner that attempts to capture the complexity of the interaction. Thus, general field methods discussed in detail in other chapters of this book should be considered when plans are made to investigate any specific research question related to the reform agenda. Such methods include teaching experiments (see chaps. 2, 11, and 12, this volume), case studies (see Cline & Mandinach, chap. 8, this volume), action research (see Feldman & Minstrell, chap. 16, this volume), developmental studies (see Battista & Clements, chap. 25, this volume), and ethnographic observational studies (see Moschkovich & Brenner, chap. 17, this volume).

Furthermore, in conducting field studies, multiple sources of evidence usually need to be gathered so that a well-grounded story can be told about the classroom situation being investigated. Studying students' understanding often will include creating construct-eliciting activities (see Hole, Hoover, Kelly, Lesh, & Post, chap. 21, this volume) or clinical interviews (see Clement, chap. 20, this volume). Studying classroom interactions may involve using video equipment for data collection and analyses (see chaps. 23 and 24, this volume).

## SUMMARY

If the education goals for the schools of America (U.S. Department of Education, 1991b) are ever to be met, considerable research needs to be carried out. The reform expectations involve creating classrooms that promote student understanding of mathematics and science. To bring about such reform, numerous investigations derived from a set of questions need to be carried out. What has been argued in this chapter is that to conduct such studies involves following field methods of inquiry utilizing multiple sources of evidence.

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